

APPENDIX A

SEDIMENT CLASSIFICATION RESULTS

Acoustic Seabed Classification Survey

- **Spokane, Washington, USA**

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EXECUTIVE SUMMARY

Acoustic seabed classification data were collected on the Spokane River in Washington State using the QTC VIEW™ seabed classification system. The purpose of the survey was to use seabed classification technology to map sediments of special interest. The area of study was surveyed using the QTC VIEW™ connected to a normal-incidence, single-frequency echo sounder. These data were then post-processed using Quester Tangent's acoustic waveform processing toolkit QTC IMPACT™. An unsupervised catalogue was generated by analysing a representative subset of the population of echoes to determine logical groupings or echo classes. The data were classified with respect to the catalogue and plotted as colour points along the vessel track.

INTRODUCTION

Acoustic seabed classification is the organization of seabeds into discrete units based on characteristic acoustic responses generated by an echo sounder (Collins and McConnaughey, 1998). The echo signal shape is the profile, over time, of the acoustic energy redirected to the echo sounder transducer. This energy is influenced by features of the seabed and immediate subsurface.

The QTC VIEW™ seabed classification system was used to map the acoustic character of the Spokane River just to the east of the City of Spokane located in eastern Washington State. The purpose of the survey was to locate soft sediments in a fluvial environment.

This report consists of an introduction to acoustic seabed classification followed by a description of the survey operations, the survey area and the equipment used. Data processing techniques are presented including data description, data reduction, catalogue generation and classification.

THEORY OF ACOUSTIC SEABED CLASSIFICATION

The amplitude and shape of an acoustic signal reflected from the sea floor is determined by the sea bottom roughness, the contrast in acoustic impedance between water and sea floor, and perturbations caused by inhomogeneities in the substrate's volume. Remote seabed classification requires an acoustic data acquisition system, an algorithm set to analyze the data, an implementation method to determine the seabed type, and ground truth to relate the acoustic classification to seabed features.

The QTC VIEW™ seabed classification system typically uses the signal from a normal incidence, single-frequency echo sounder (Collins et al., 1996). The system is connected in parallel with the echo sounder transducer and digitally extracts the echo trace. Pre-processing involves identification of the sea floor in the echo trace and filtering to suppress noise.

Echo description is accomplished using several algorithms to extract 166 echo shape features, known as full feature vectors (FFVs), from each trace. Multivariate statistical analysis then identifies the best feature combinations to distinguish groups of echoes representing different seabeds. The feature combinations are reduced to three primary values, known as Q-values, which describe each echo.

Echo classification is accomplished using the three Q-values; it is assumed the acoustic response from like seabeds will be similar. When Q1, Q2 and Q3 are plotted in orthogonal Q-space, seabeds with similar acoustic responses will form clusters. An echo is classified using its position in Q-space with respect to the clusters generated from calibration data; the echo being classed the same as the closest cluster.

The echo classification in Q-space was done without prior knowledge of the sediment at the sites. Therefore, without a catalogue associating clusters to sediment type, unsupervised classification was used to statistically generate clusters from Q-values alone.

The final step was to use these results to generate a catalogue, and to reprocess the echoes from each area according to this catalogue.

Effect of Seabed Features on Signal Shape

The primary role of an echo sounder is to measure water depth. Details of the echo are usually ignored. Quester Tangent bottom classification is based on these details, which contain information about the bottom type. This necessitates considerations with the returning echo's shape when mapping the sea floor. For example, the echo from a smooth, simple seabed has a sharp rise and a peak followed by a short tail. The response from a rough, complicated seabed will be a peak followed by a slower decay in the signal represented by a longer tail (Figure 1).

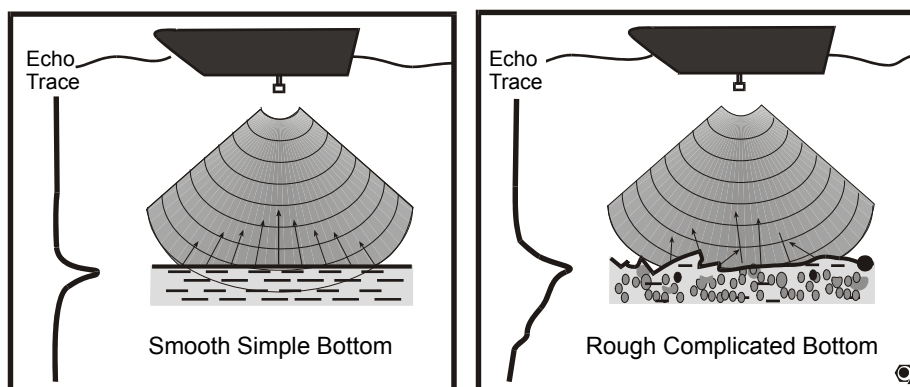


Figure 1: Comparison of echo traces from two representative seabeds.

While the shape of the returning waveform is related to the target (i.e., sea floor sediments), there are numerous characteristics accounting for the seabed's variability (Figure 2). These include organisms living on or in the seabed. Sedimentary bedforms, such as ripple marks, will influence the echo as will sediment properties including grain size and index properties, such as porosity and density. The signal's shape will be a composite of the above features averaged over the footprint.

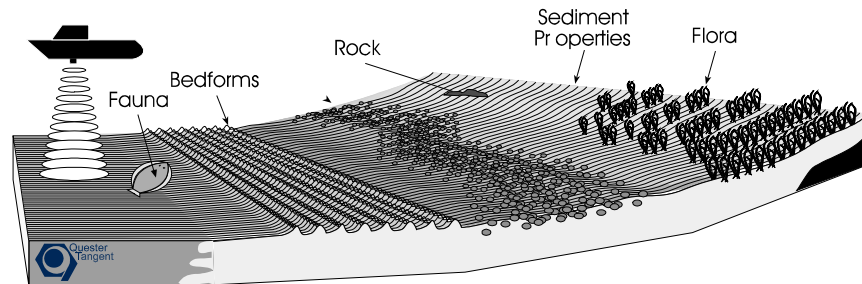


Figure 2: Features of a typical seabed influencing the acoustic response.

Other Factors Affecting Seabed Classification

Sounder parameters such as beam width and frequency influence classification results (Collins and Rhynas, 1998). Beam width is a measure of the size of the conical shaped path of the transmitted echo pulse. The size of the seabed acoustic footprint is a function of the beam width and the water depth. Frequency is a characteristic of the carrier signal used for insonification. Frequency governs the passage of the acoustic pulse through both water and sediments, and determines the resolution of the data returning to the sounder. High frequency signals (>100 kHz), typically provide greater resolution, suffer greater attenuation in the water column and penetrate centimetres into the seabed depending largely on substrate reflectivity. High frequency transducers have typically smaller beamwidths (10° - 20°). Low frequencies, 10 kHz to 100 kHz, resolve less than the higher frequencies, exhibit smaller signal losses in the water, and will penetrate tens of centimetres into the seabed. Low frequency transducers generally have larger beamwidths (15° - 30°).

SURVEY OPERATIONS

Description of Survey Area

The survey area is located in Eastern Washington State on the Spokane River. The survey was done simultaneously to a bathymetric survey. Water depths range from approximately one to 12 meters.

Equipment

This survey was performed using an aluminium jet boat (Figure 3). The vessel is fully equipped for hydrographic surveying including an echo sounder, a data management and navigation software package and, a two GPS's each providing positioning to QTC View Series V seabed classification system and its management software running on a PC.



Figure 3: Survey Vessel

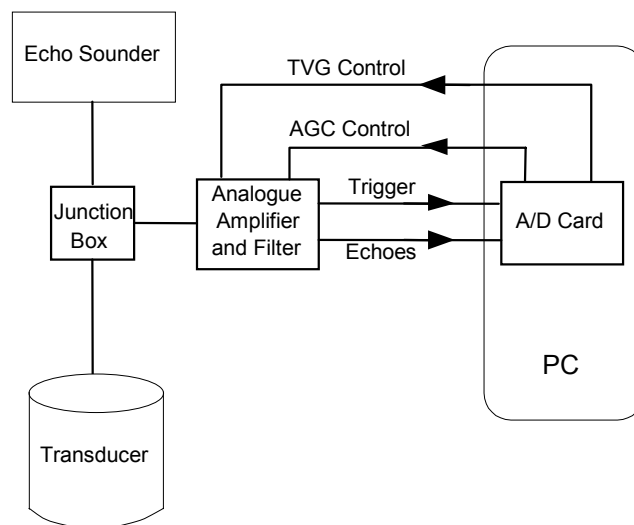


Figure 4: Interconnection diagram for the QTC VIEW™ system.

A Suzuki 2025 echo sounder @ 50 kHz was used for QTC VIEW™ data acquisition. Table 1 outlines the relevant parameters for seabed classification.

A QTC VIEW™ Sounder Interface Module (SIM) was connected in parallel to the echo sounder's transducer (Figure 4). The SIM was also connected to the seabed classification system's computer via a SCSI-like connection to an A/D card. During acquisition both the navigation and sonar data were simultaneously time-stamped and logged to the computer.

ECHO SOUNDER	
Name	SUZUKI 2025
Frequency	50 kHz
Depth Range	0 – 20 m
Ping Rate	7 per second
Pulse Duration	0.3 ms
Beam Width	42 degrees

NAVIGATION	
Update Rate	1 per second
Record Type	\$GPGGA

Table 1: Echo sounder and navigation parameters

Data Acquisition and Quality Control

The area was surveyed from May 21 to May 22, 2003 with the QTC VIEW™ acoustic seabed classification system. The system digitally acquired each raw echo at a rate of approximately seven per second and logged the waveform for post-processing. GPS navigation data were simultaneously logged as comma-delimited ASCII records which in this case were a NMEA GPGGA string. In post-processing, the sonar and navigation records were merged based on a high resolution time-stamp

tagged to each record at the time of logging. During acquisition, the sonar envelopes were observed in a real-time viewer to assess quality of the signal, system gain and the depth pick. By viewing the sonar data in real-time the operator can access the “look” of the echoes for both signal to noise issues and bottom picking problems. Both the full waveform (FWF) and envelope data were logged by the system. The sonar data were stored in a QTC proprietary format.

DATA PROCESSING

Sonar and navigation data processing was facilitated using QTC IMPACT™. The flow of data processing is displayed in Figure 5. The seabed classification process includes quality assurance by viewing the raw echo traces, extraction of feature set to be used as echo description, principal components analysis for data reduction and cluster analysis to identify acoustic regimes which were then assigned to an acoustic class.

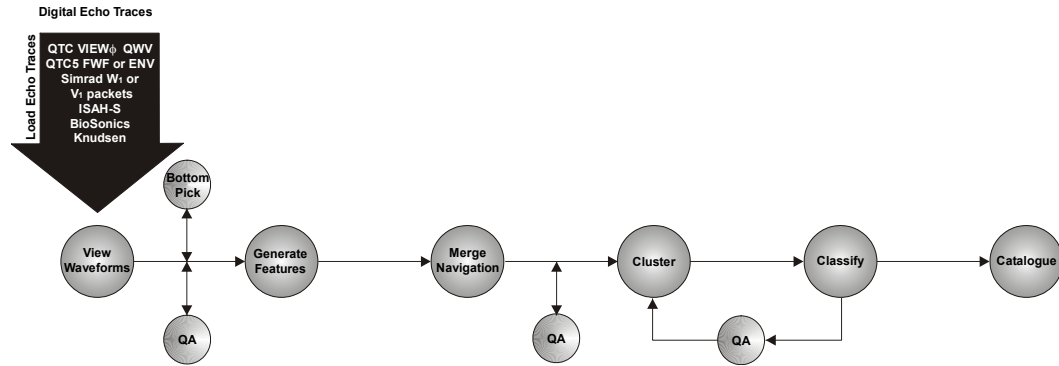


Figure 5: Data processing flow diagram

Data Quality Control

A critical step in processing the data prior to classification is quality assessment. The Full Waveform (FWF) data are the fundamental data transmitted by the echo sounder and therefore contain the most information. The raw waveforms are first loaded and viewed to determine if they are reasonable. Once the raw data have been viewed, bottom picking parameters may be altered and applied to the data for a first order of cleaning.



Figure 6: High quality FWF data. The bottom pick is indicated by the horizontal red line.

The group of waveforms in Figure 6 are representative of good quality full waveform data with a red line indicating the depth the waveform was recorded. Figure 7 shows the waveform DSN #2 from Figure 6 in a single trace viewer. In this view a user can see the details of the waveform and also the amplitude of the signal in samples. QTC VIEW™ Series V data is 12 bit data so the maximum signal amplitude is 2048 samples.

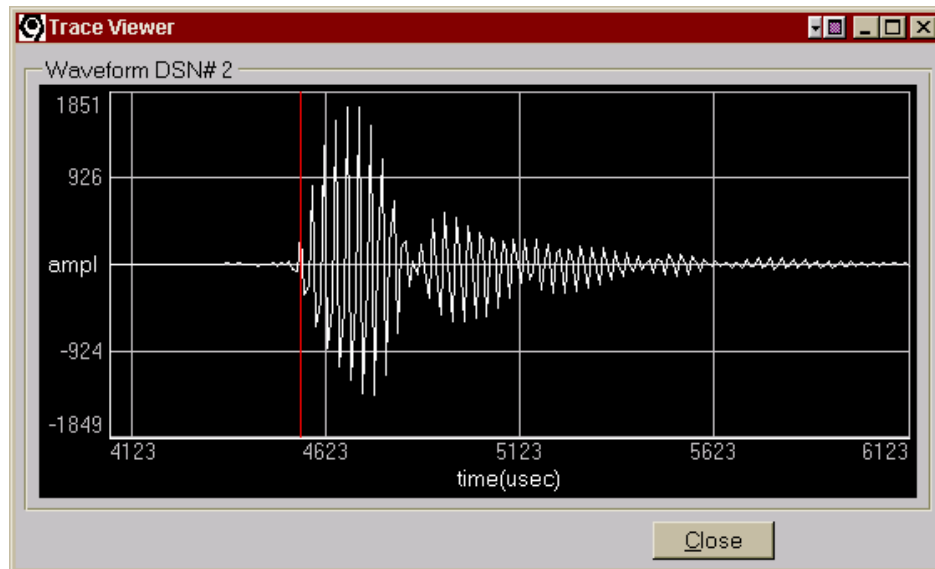


Figure 7: Single echo trace from Figure 6. The bottom pick is indicated by the vertical red line.

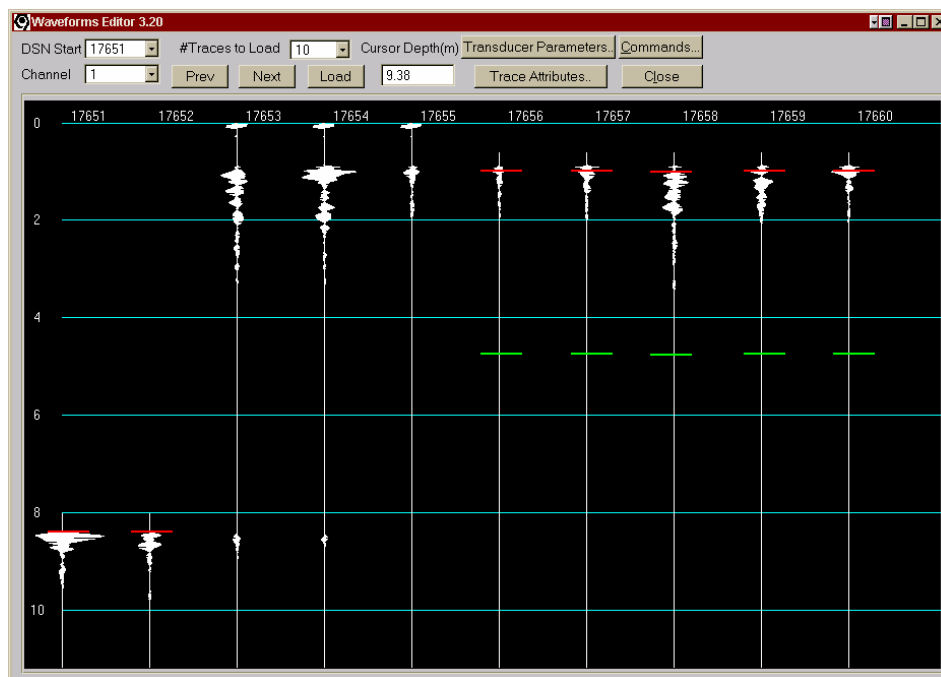


Figure 8: An area of abrupt change from high to low quality data.

Figures 8 and 9 are examples of poor quality FWF data. The waveforms in Figure 8 are of low signal amplitude and three of the echoes do not have a bottom pick associated with them. Those three echoes will not be carried into the next step of processing, envelope generation.

Figure 9 displays a single trace from Figure 8 showing the cause of the poor data was the signal was locked onto the transmit pulse. The initial pulse (on the far left) is the transmit pulse. The second pulse is not the return from the bottom but rather more of the same transmit pulse and transducer ring-down time. This data is of poor quality because the transmit pulse is visible and there is no bottom pick (normally indicated by a red line) associated with this trace.

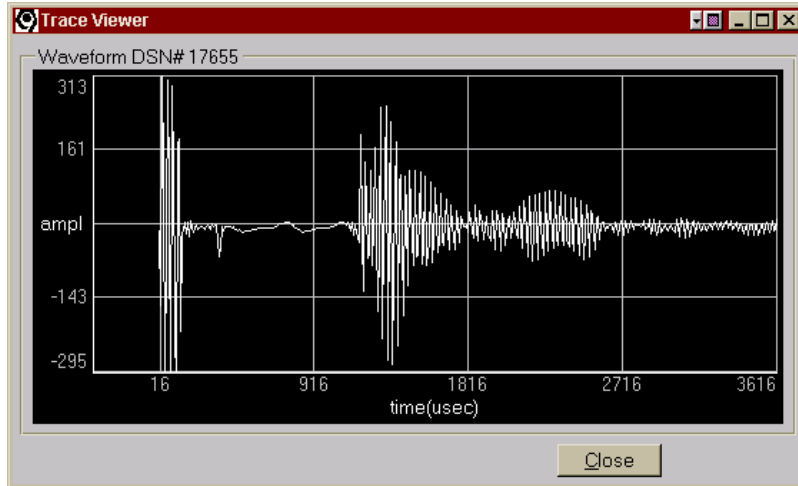


Figure 9: An individual echo trace from the low quality region of Figure 8.

Once all of the full waveform data has been loaded and evaluated QTC IMPACT™ will reduce the data to create a new envelope data set. Figures 10 and 11 show good quality envelope data.

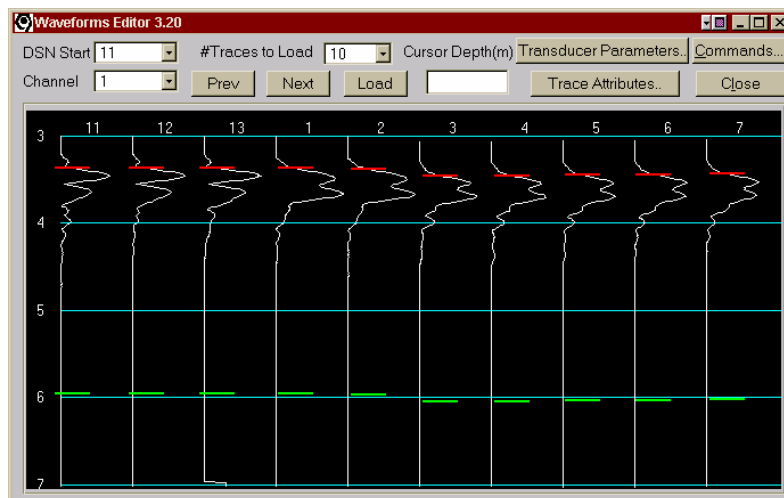


Figure 10: Waveform Editor showing high quality envelope data.



Figure 11: A detailed view of one echo trace from Figure 10.

Figure 12 is the trace attributes window which is available in the waveform editor for both FWF data and envelope data sets. This window gives a user valuable qualitative and quantitative information on each waveform. The time stamps can be used to determine how fast the system logged data or by using the signal strength as a percentage, the signal amplitude as a ratio of the maximum signal possible can be seen.

File ID	DSN#	Time	Trace Type	Pick Sample#	Holdoff Metres	Depth (m) w/o Draft	Depth (m) w/ Draft	Sample Int (usec)	Signal Strength %
0	11	10:38:59:500	1	342	3.17	3.54	3.54	13.79	57
0	12	10:38:59:780	1	342	3.17	3.54	3.54	13.79	61
0	13	10:39:00:060	1	342	3.17	3.54	3.54	13.79	66
1	1	10:54:45:560	1	342	3.17	3.54	3.54	13.79	78
1	2	10:54:45:850	1	343	3.17	3.55	3.55	13.79	78
1	3	10:55:52:320	1	349	3.24	3.62	3.62	13.79	65

Figure 12: Trace attribute window for Figure 10.

Envelopes are evaluated and if necessary the same bottom picking options available for FWF can be run on the envelope data if it is determined that the data needs to be re-picked. The bottom pick is very important because it is the starting point for the next step in the process to reduce the data by fitting it into a smaller digitisation window. Table 2 illustrates the bottom picking parameters used on these data and Figure 13 illustrates a low amplitude signal that will not be used in the next processing step.

Bottom Picking Parameters	
Channels	All
Traces	All
Threshold (%)	35
Blanking (m)	0
Gate Above	5
Gate Below	5
Gate Average	100
Gate Minimum	0

Pick Mode	LOOK_ABOVE
Pick Operation	Pick All Traces

Table 2: Bottom pick parameters.

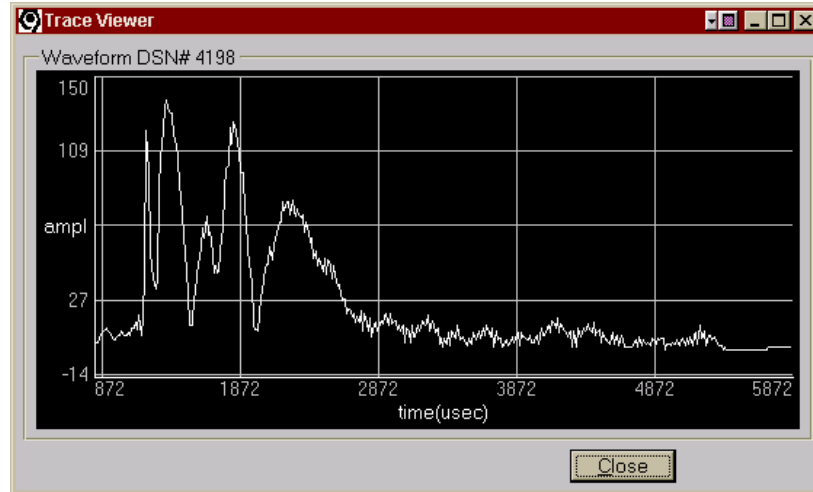


Figure 13: Echo trace with very low signal strength, less than 150 out of a possible 2048.

Waveform Data Reduction

This process reduced approximately 180,000 sonar envelopes to 36,000 records called Full Feature Vectors (FFV). Each FFV is comprised of 166 parameters that describe each individual echo and were derived from Quester Tangent's suite of algorithms. In preparation for the next level of data cleaning each FFV was merged with the closest position record.

The next step of quality assessment occurs after Full Feature Vectors (FFVs) are created. Using the FFV editor, the FFVs were viewed with respect to different parameters. These data were viewed by depth (Figure 14), stack span (Figure 15) and time span (Figure 16). The FFVs can be readily cleaned in either the FFV Editor or by utilising the FFV Filter. It is important to note that none of the FFVs are removed. The FFV records are flagged as rejected or filtered and then excluded from classification. Data displayed as green dots are the good quality data; data displayed as yellow or red have been flagged and will not carry on any further in the classification process. The parameters used for FFV filtering are outlined in Table 3. The resulting file was used to define a reference set for making a catalogue of seabed classes across the survey site.

FFV FILTER PARAMETERS	
Depth	Excluded depths less than 0.90 meters
Stack Span	Excluded stack spans greater than 0.50 meters
Time Span	Excluded time spans greater than 1000 ms

Table 3: Listing of FFV filter parameters.

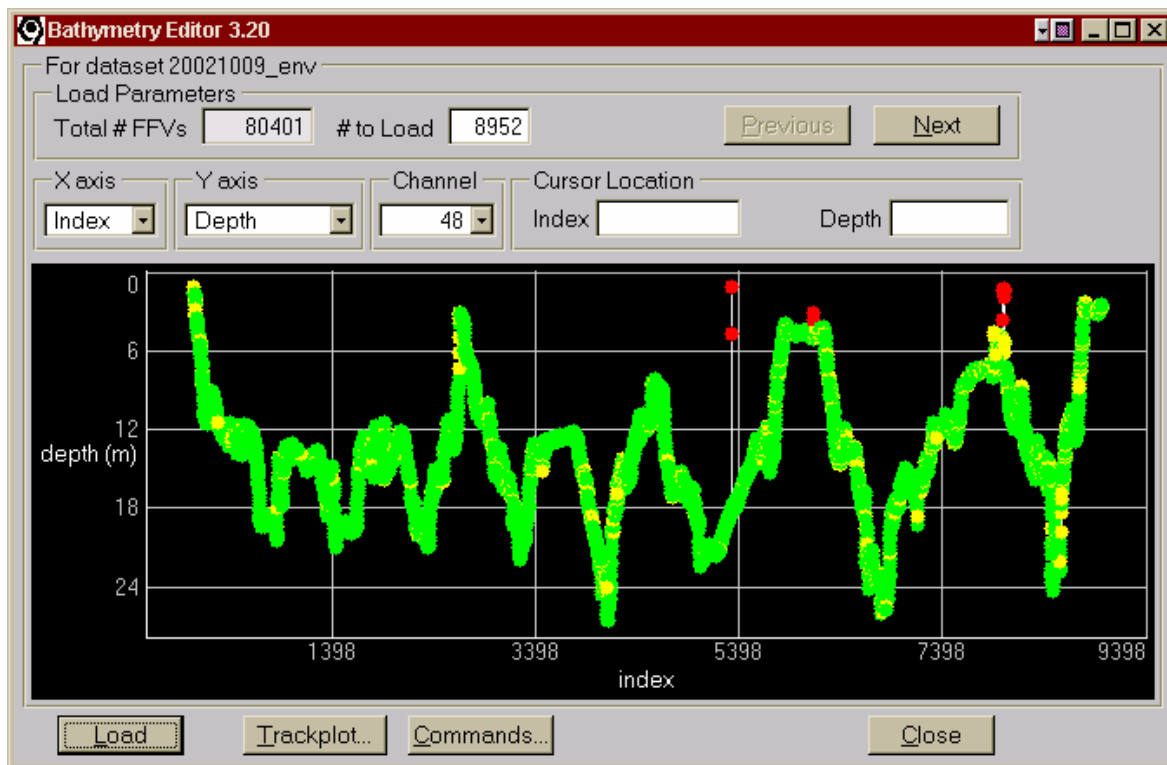


Figure 14: Depth view in FFV Editor

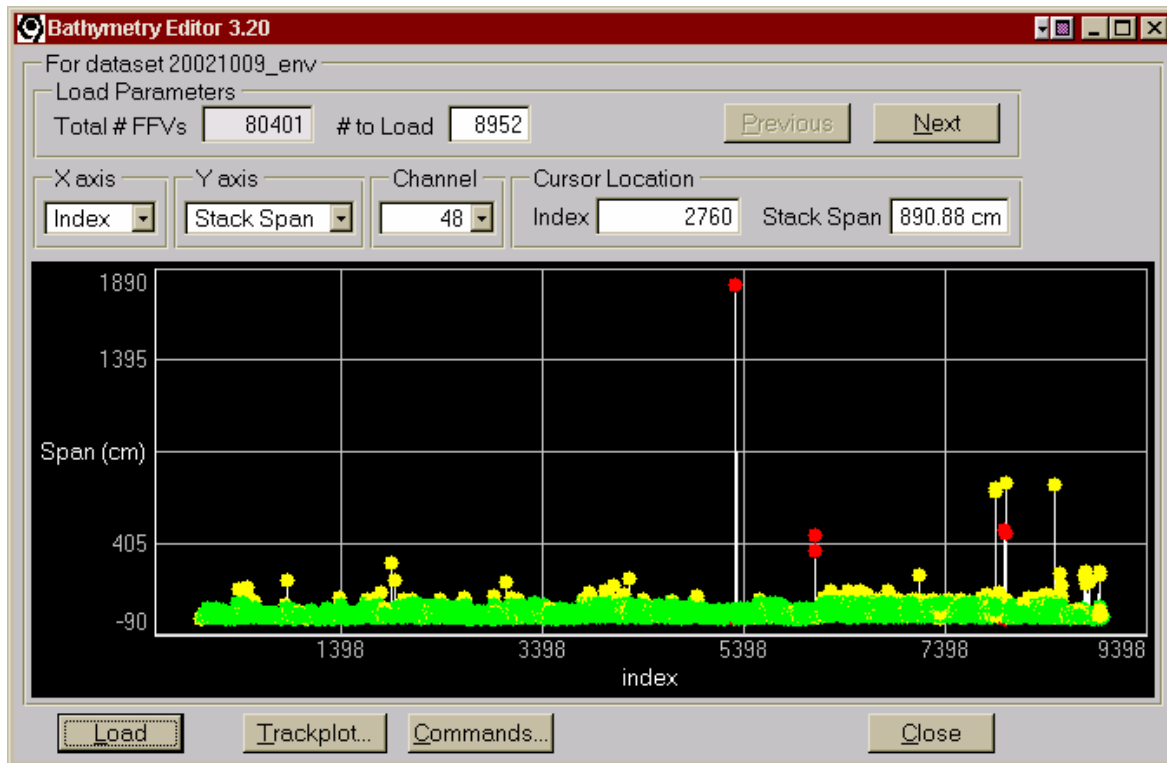


Figure 15: Stack span view in FFV Editor

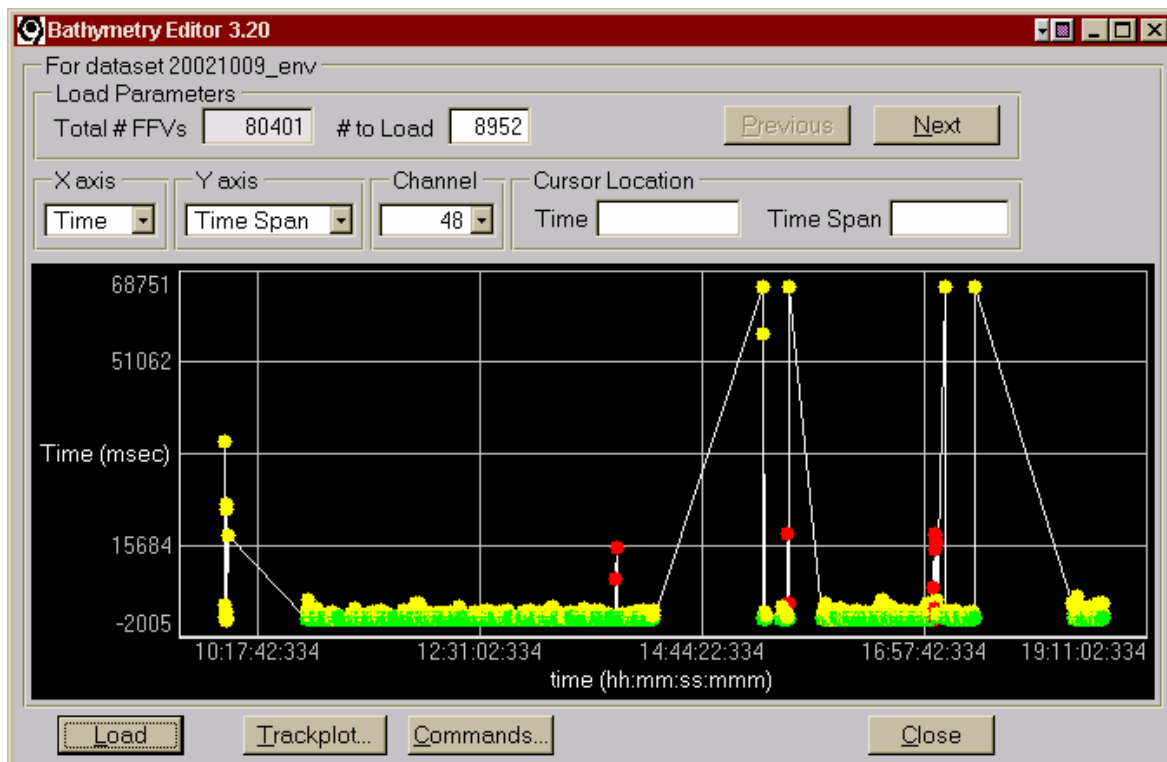


Figure 16: Time span view in FFV Editor.

Reduced Feature Data and Catalogue Generation

Each FFV record from the reference set was reduced to three Q-values using a multivariate statistical technique. The Q-values were then submitted to a proprietary cluster tool to identify logical populations of echoes. Seven populations of echoes were identified in the data. The data were displayed in Q-space as coloured points, each colour representing an acoustic class (Figure 17). Wire-mesh ellipsoids representing a surface one standard deviation from the mean of each cluster were also shown to indicate class covariance.

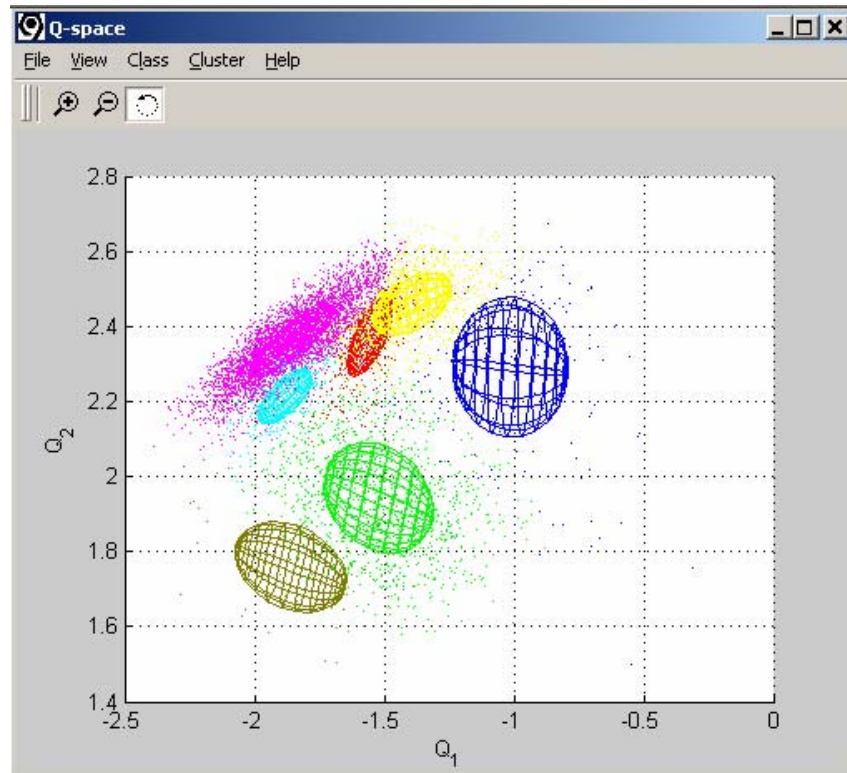


Figure 17: Plot of Q-space with data points from catalogue.

Once the clusters were determined, their mathematical description was stored with the results from the multivariate analysis, used to reduce the FFV information to the three Q-values, to comprise the catalogue. This catalogue was then used in preparing the final classification map.

Classification

Acoustic Seabed Classification

The analysis consisted of defining seven classes using the raw echoes collected during the survey. The resulting data file was merged with the position information to generate a geo-referenced classification data set constituting the final data product. The file format was a comma-delimited text file, known as a seabed file, containing processing date, time stamp, latitude and longitude in decimal degrees, depth, Q_1 , Q_2 , Q_3 , confidence, probability, classification number, classification name, source survey name, source date stamp, source data set name, source FFV file channel, and source FFV file record index. Table 4 presents a sample of this comma delimited ASCII file. A map of the seven classes was produced (Figure 18).

20030520,133421840,-117.32722702,47.68643408,-8.30,-2.23926377,2.08282042,-0.79392362,99,01,04,CLASS_04,SPOKANE,20030520,tester,1,1292

20030520,133422550,-117.32722109,47.68642568,-8.46,-2.36959934,1.95746148,-0.98410451,50,00,04,CLASS_04,SPOKANE,20030520,tester,1,1293

20030520,133423260,-117.32721506,47.68641722,-8.41,-2.33014512,1.95622861,-1.04504204,75,00,07,CLASS_07,SPOKANE,20030520,tester,1,1294

20030520,133423970,-117.32720924,47.68640836,-8.43,-2.24830866,1.96438158,-1.07395613,88,00,07,CLASS_07,SPOKANE,20030520,tester,1,1295

20030520,133424680,-117.32720319,47.68639910,-8.40,-2.01387453,2.27647543,-0.77166575,99,12,04,CLASS_04,SPOKANE,20030520,tester,1,1296

20030520,133425390,-117.32719741,47.68638934,-8.38,-2.23091841,2.11201191,-0.90129972,99,00,04,CLASS_04,SPOKANE,20030520,tester,1,1297

20030520,133426100,-117.32719156,47.68637930,-8.29,-2.62090969,1.94762409,-0.92601120,62,00,07,CLASS_07,SPOKANE,20030520,tester,1,1298

20030520,133426810,-117.32718539,47.68636900,-8.03,-2.43614101,2.00949860,-0.85239559,94,00,04,CLASS_04,SPOKANE,20030520,tester,1,1299

20030520,133427520,-117.32717895,47.68635859,-7.97,-2.31445694,2.09580159,-0.77906317,99,01,04,CLASS_04,SPOKANE,20030520,tester,1,1300

20030520,133428230,-117.32717247,47.68634777,-7.72,-2.05972266,2.15691590,-0.80193830,99,06,04,CLASS_04,SPOKANE,20030520,tester,1,1301

20030520,133428940,-117.32716579,47.68633673,-7.64,-2.40431237,1.93982732,-1.02355969,70,00,07,CLASS_07,SPOKANE,20030520,tester,1,1302

20030520,133429650,-117.32715858,47.68632574,-7.49,-2.04311752,2.19371939,-0.75175220,99,18,04,CLASS_04,SPOKANE,20030520,tester,1,1303

20030520,133430350,-117.32715150,47.68631451,-7.48,-2.14350843,2.11589289,-0.97220635,98,00,04,CLASS_04,SPOKANE,20030520,tester,1,1304

20030520,133431060,-117.32714384,47.68630319,-7.38,-2.32310724,2.03209829,-0.90839708,96,00,04,CLASS_04,SPOKANE,20030520,tester,1,1305

20030520,133431780,-117.32713532,47.68629165,-7.20,-2.08355212,2.22897673,-0.68759227,99,35,04,CLASS_04,SPOKANE,20030520,tester,1,1306

20030520,133432490,-117.32712685,47.68628023,-7.18,-2.31721735,2.01690412,-0.99946922,79,00,04,CLASS_04,SPOKANE,20030520,tester,1,1307

20030520,133433200,-117.32711769,47.68626874,-7.14,-2.20234942,2.12798238,-0.78820032,99,04,04,CLASS_04,SPOKANE,20030520,tester,1,1308

20030520,133433910,-117.32710808,47.68625714,-7.09,-2.26184964,2.02977133,-1.01256382,81,00,04,CLASS_04,SPOKANE,20030520,tester,1,1309

20030520,133434620,-117.32709909,47.68624550,-7.08,-2.07085466,2.21186614,-0.72339731,99,29,04,CLASS_04,SPOKANE,20030520,tester,1,1310

20030520,133435330,-117.32708934,47.68623376,-6.94,-2.18921971,2.21549177,-0.68944275,99,10,04,CLASS_04,SPOKANE,20030520,tester,1,1311

Table 4: Final data file format

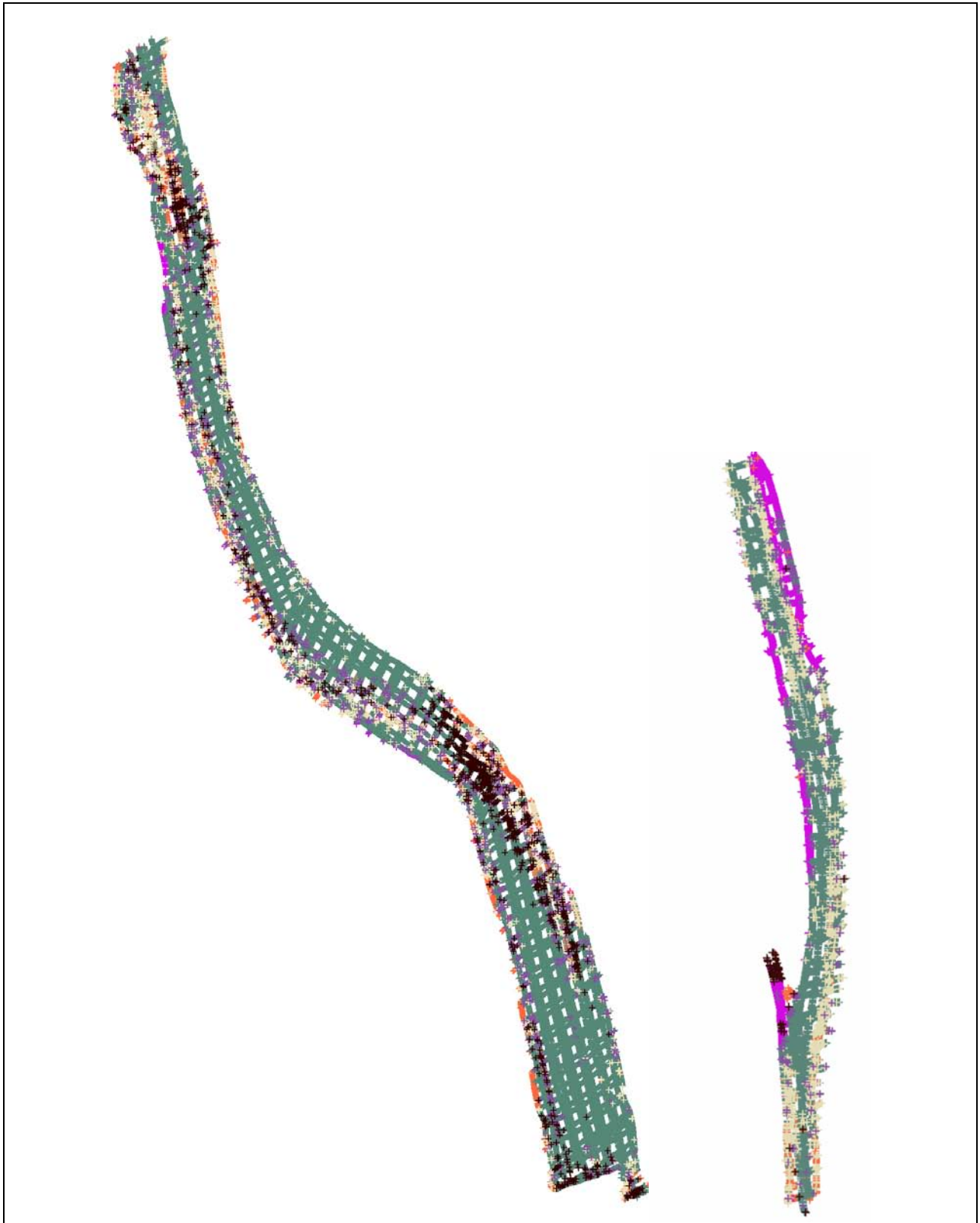


Figure 18: Acoustic classification data-Total survey area

Eastern Survey Area Interpolation

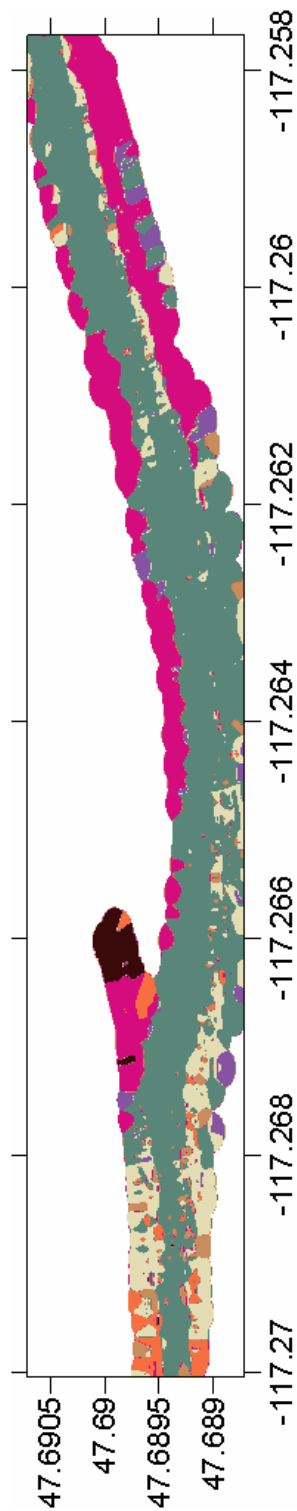


Figure 19: Interpolated classification data

SUMMARY

Seabed classification is the organization of seabed types into discrete units based on characteristics of the acoustic response. The QTC VIEW™'s unique approach to seabed classification involves the digitization of the echo trace from an echo sounder, and generation of descriptors of the echo shape, followed by classification based on statistical processing. If ground truth is available, it can be used to validate the classification.

The transmitted signal from the echo sounder and the first returning echo are captured and digitized by QTC VIEW™. The digital signal is then processed by a series of algorithms sensitive to different components of the echo shape. This processing generates 166 features of the echo trace, which make up a Full Feature Vector record describing the trace. Statistical analysis provides a means by which the 166 features can be reduced to three so-called Q-values. Each echo, as represented by three Q-values, can be plotted in three-dimensional Q-space. Echoes from acoustically similar seabeds will form discrete and definable clusters when plotted in Q-space. The information used to reduce the 166 feature elements to the three Q-values are stored in a catalogue. Full Feature Vectors, describing echo traces, are then classified according to the classes defined in the catalogue.

Acoustic seabed classification data were collected by Blue Water Engineering May 21-22, 2003. Seven discrete acoustic regimes were identified and displayed along the vessel track lines.

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